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Getting the Most from the Twin Mars Rovers

- **MAPGEN automatically generates activity plans for rovers**
- **Decision support system mixes autonomous planning/scheduling with user modifications**

Did Mars ever contain water? To find out, NASA's Mars Exploration Rover (MER) mission has sent two rovers to two locations on Mars. Each rover is equipped with nine cameras and an instrument-packed robotic arm to assist in its search for evidence that Mars contains, or once contained, water—the medium for life as we know it. Since each rover's mission is scheduled to last only about 90 days, it is critical to make the most of rover time and resources.

To help meet this challenge, the CICT Program's Intelligent Systems (IS) Project has funded development of a ground-based planner/scheduler called MAPGEN, or Mixed-initiative Activity Planning GENerator.

"The rovers are supervised by 240 scientists and engineers from different disciplines and with different goals," says Robert Morris, manager of the IS Project's Automated Reasoning subproject. "The team downloads data from the rovers each evening and have about 16 hours to analyze the data, decide the next day's agenda, and upload new instructions to the rovers before morning. Speed, efficiency, and consistency are essential to the science planning, and MAPGEN helps provide that."

Accommodating change

"Science is the primary driver of the MER mission," says Kanna Rajan, principal investigator and project lead for MAPGEN. "Therefore, it's crucial to make the best use of the rovers' scientific instruments within the constraints of the available resources. The rovers operate on solar power, so the amount of science done on each Martian day, or *sol*, is highly constrained by their onboard resources.

"Our challenge was to develop a decision-support system for rover planning that within a short time frame could automatically calculate an ordering relationship between activities and the resources to develop a flexible plan that provides maximum efficiency. We also had to enable the human operators of the system, the Tactical Activity Planners (TAPs), to modify the plans to accommodate scientific intent or changes in resources, all without violating engineering or scientific constraints to maintain the health and safety of the rovers."

Combining the best of two systems

Rajan's team met the challenge by combining and adding features to two proven NASA planning systems: APGEN, a manual activity planner developed by NASA's Jet

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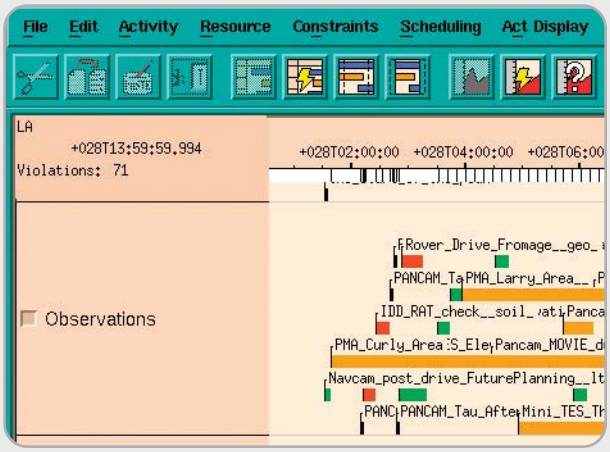

MAPGEN's user interface (detail, left) shows a rover's planned activities for the day and the resulting energy profile of available battery power (not shown in detail). The operator can manually edit the plan before uplink to the rover, and MAPGEN will readjust the energy profile and warn of any rule violations.

Technology Spotlight

Technology

MAPGEN (Mixed-initiative Activity Planning GENerator)

Function

Supports operations team in planning goals, analyzing resources, and editing plans for scientific and engineering robot activities

Relevant Missions

- Mars Exploration Rover
- Activity planning for future Exploration Systems Enterprise robotic missions

Features

- Automatically generates plans and schedules for scientific and engineering activities
- Enables humans to edit plans and even override some constraints when required
- Supports "what if" hypothesis testing
- Tracks and considers resource availability in planning process
- Maintains and enforces flight rules and scientific constraints

Benefits

- Simplifies the planning process
- Speeds planning by reducing ground controller workload
- Provides consistency and robust support to a multi-person team
- Enables more complex and robust missions

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Controlling the rover from Earth, the Mars Exploration Rover (MER) operations team sends up instructions to the rover (left), telling it which geological features to inspect. The team uses MAPGEN to assist them in developing plans for each day's activities.

Propulsion Laboratory, and Europa, an automated planning/scheduling system developed at NASA Ames Research Center to fly on Deep Space One as part of the Remote Agent experiment. MAPGEN leverages the strengths of both APGEN and Europa to provide a mixed-initiative system that takes input from the automated planner and the human TAPs to automatically build a violation-free plan.

One of the team's primary integration challenges was to reconcile the APGEN interface with the Europa planner. Whereas the interface can display only a single plan with fixed activity start times, the planner representation encapsulates multiple plans that conform to current constraints and resources. The team designed MAPGEN to present a single "candidate" plan to the interface, one that assigns to each activity the earliest start time possible. Meanwhile, the underlying planner maintains a flexibility that the TAPs can use to generate qualitatively different plans.

Constraints and preferences

MAPGEN uses constraints that are based on engineering, or "flight," rules and science preferences. Flight-rule constraints are built into MAPGEN and can include rules such as "Don't take a picture when the rover is traversing." Science preference constraints are entered via a constraint editor that Rajan's team built for the scientists. These science constraints encapsulate what the scientists want the rover to do within the plan, and when, such as "Take a panoramic picture of the surrounding landscape between 10 a.m. and noon to compensate for any light effects."

Activity ordering decisions are then imposed by MAPGEN to comply with these flight rules and science constraints. For example, to comply with the flight rule, "No pictures can be taken while the rover is moving," MAPGEN will order one or the other activity first—move the rover and then take a picture, or take a picture and then move, assuming that there are no "time of Sol" constraints on when to take a picture. If desired, the TAP can choose to manually reorder the activity.

Additionally, scientists can prioritize rover observations, and MAPGEN will accommodate these priorities in its planning. When lower-level priorities do not fit in a plan, MAPGEN consigns them and their subordinate components to a temporary "hopper." If necessary, the TAP can retrieve them from the hopper and manually reinsert them in place of another activity or ask for their automatic retrieval and insertion into the plan.

Other preferences may be input to MAPGEN during the day's activities to take advantage of available resources or to provide a short-term solution to a transient problem. "This is where the human operator surpasses the automated planner, and the notion of *mixed-initiative* interplay between the software and the human operator comes into play," says Rajan.

MAPGEN's mixed-initiative features

MAPGEN includes features that enhance this mixed-initiative paradigm. A *constrained move* feature allows the TAP to edit the current plan by dragging an activity to a new time location, as long as it remains within the constraints enforced by MAPGEN. As the TAP drags an activity to a new position, all subordinate components of the activity automatically move with it. The planner then tightens the window for that activity, and relocates the other activities in the most efficient manner possible. This relieves the TAPs of low-level planning overload, while enabling them to focus their expertise and judgment on higher-level tasks. Additional features enable the TAP to override flight rules and science preference constraints if necessary.

Rajan's team has also developed another feature that is still pending use. It enables the TAP to have MAPGEN automatically reorder activities to exploit (and/or preserve) the rover's current battery charge, the most critical and non-linear resource on the rover.

Demonstrated success

MAPGEN has already been used to check the Spirit rover's egress from its lander on Mars. The first MAPGEN activity plan for the rover, described as "exceptional" by the Mars team, was approved and successfully executed.

According to the MER mission's principal investigator, Steve Squyres, "The planner is doing exactly what we want it to do and doing it well."

Mapgen is a breakthrough in automated support for human operators in planning robotic activities, and is a key component in enabling the Mars rovers to search effectively for evidence of water on Mars.

—Larry Laufenberg

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